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New Astrometric Reduction of the USNO Photographic Plates of Planetary Satellites

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Abstract. An international collaboration has been set up between the US Naval Observatory (USNO) in Washington DC, the IMCCE of Paris Observatory (OBSPM) and the Royal Observatory of Belgium (ROB) to make a new astrometric reduction of the USNO archival photographic plates of planetary satellites. In order to obtain a better knowledge of their orbital motions these photographic plates are digitized with the new generation DAMIAN digitizer at the ROB, providing a geometric stability of better than 0.1 μm on the plates. We focus here on a subset of a few hundred photographic plates of the Galilean satellites, taken with the McCormick and the USNO 26-inch refractors between 1967 and 1998. Specific procedures and algorithms are used to obtain highly accurate positions using the Tycho2, UCAC2 (20 - 30 mas) and later the UCAC3 (10 - 20 mas) catalogues. A comparison with the MAMA digitizer of the Paris Observatory is made through the results obtained from digital mosaic images of the plates.

1. The DAMIAN - Digital Access to Metric Images Archives Network - Digitizer

The building of a 2D-digitizer facility of high geometric and radiometric accuracy and repeatability, started under the D4A pilot-project (De Cuyper et al. 2004; De Cuyper & Winter 2005, 2006), has continued. In autumn 2007 the DAMIAN digitizer was installed and housed in a temperature and humidity stabilised clean room with adjacent archive room. The DAMIAN machine can digitize photographic images up to 350 mm wide on glass plates, film sheets and film rolls.

The XY-table, an engineered Aerotech ABL3600 air bearing system, has a positioning accuracy and repeatability better than 0.1 μm. This fulfils the aimed submicron accuracy for digitizing astrometric photographic plates (Zacharias et al. 2003; Zacharias & Urban 2004). The mechanical subsystem includes an automatic plate holder assembly, a plate tray exchange robot with plate tray

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magazine and turntable for photographic glass plates and film sheets and an automatic film roll transport system. These custom-made devices allow a rapid change and loading into focus of the photographs to be digitized without manual intervention. The optical system consists of a BCi4 12 bit CMOS camera from C-Cam Vector International mounted on a Schneider Xenoplan telecentric 1:1 objective. The back light illumination system uses very bright LED's (minimum lifetime 50,000 hr), controlled by a precision power supply.

2. Digitization of USNO Plates of the Galilean Satellites

A set of multiple-exposure observations of the Galilean satellites, taken with the McCormick (1967/68) and the USNO (1973 - 1998) 26 inch refractors on Kodak 103aG plates (scale: 20.8 mas/μm) by Pascu (1977, 1979, 1994), were digitized both with the MAMA (OBSPM) and the DAMIAN (ROB) digitizers. The MAMA has a 1D Recticon detector with 1024 10 μm pixels used in scanning mode. Individual subimages without overlap of 1024×1024 pixels are generated after a refocus in the middle of each subarea (Berger et al. 1991; Guibert 1991). The DAMIAN has a 2D CMOS camera with 1280×1024 7μm pixels used in step and stare mode with a stable preset focus. The stepping is done in a zig-zag pattern of exactly 704 pixels in the X and Y direction. A non-overlapping mosaic image of the whole plate was generated from these subimages after dark and flat correction.

The positions of the Galilean satellites and the stars in the mosaic images were extracted by means of the Sextractor software (Bertin & Arnouts 1996). The obtained positions in pixel space were transformed into celestial coordinates through a least squares fitting of the stellar positions using the UCAC2 catalogue (Zacharias et al. 2004) after correcting for abberation and the atmospheric refraction. The estimation of the internal repeatability error of the MAMA was found to be 0.7 μm and of the DAMIAN 0.07 μm.

3. Geometric Calibration of the DAMIAN Digitizer

A dot calibration plate (geogrid) of chromium opaque dots of 50 - 300 μm diameter put in a regular grid with a 0.5 mm separation is used to determine the field of view (FOV) error of the optical system (camera and objective) and the geometric errors and the repeatability of the XY-table of the DAMIAN digitizer. The positions of the dots were extracted by means of the adapted StarScan extraction software (Winter 1999; Winter & Holdenried 2001).

The FOV error of the optical system is removed through a coordinate transform between the pixel positions on the detector and the geometric positions on the plate using a 7-parameter model (Zacharias et al. 2008):

$$\Delta X = \ ax + by + ex + fy + px^2 + qxy + dxr^2 \tag{1}$$

$$\Delta Y = -bx + ay + fx - ey + qy^2 + pxy + dyr^2. \tag{2}$$

$\Delta X, \Delta Y$ are the plate coordinates of an object expressed as differences in mm with respect to the coordinates of the XY-table as obtained from the calibrated Heidenhain encoders; x, y are the fitted pixel coordinates of this object with

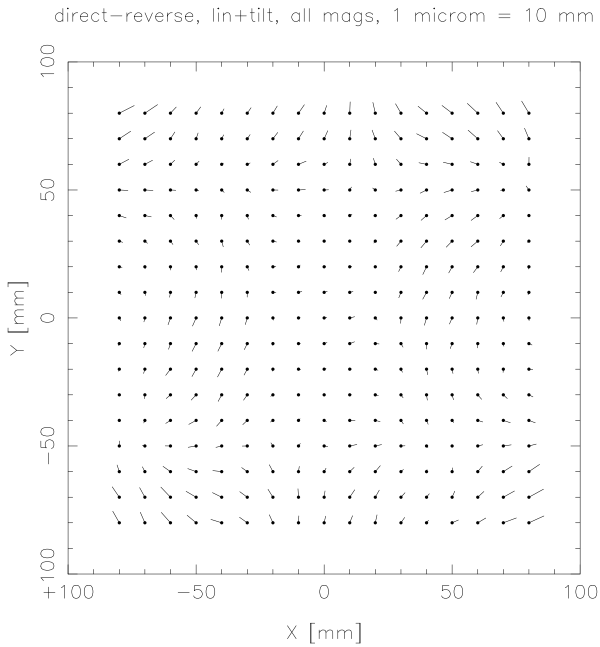

Figure 1.: The uncalibrated mean position differences between direct and reverse measures of the grid plate are shown as a vector plot. The scale is 10,000 so the largest vector is about 1 μm long.

respect to the center of the FOV of the camera; a, b are orthogonal terms; e, f are linear, non-orthogonal terms; p, q are tilt terms; d is the third-order optical distortion term and $r^2 = x^2 + y^2$. The working area used for plate measuring is about 5×5 mm. The point spread function (PSF) of images in the digital camera working area is uniform, because of the hardware setup with constant focus and the optical quality of the lens. Figure 1 shows the mean position differences between direct-reverse measures of the grid plate as function of X,Y. Figure 2 shows a small magnitude equation from the same measures. All these systematic error patterns are repeatable and can be taken out to arrive at calibrated measures.

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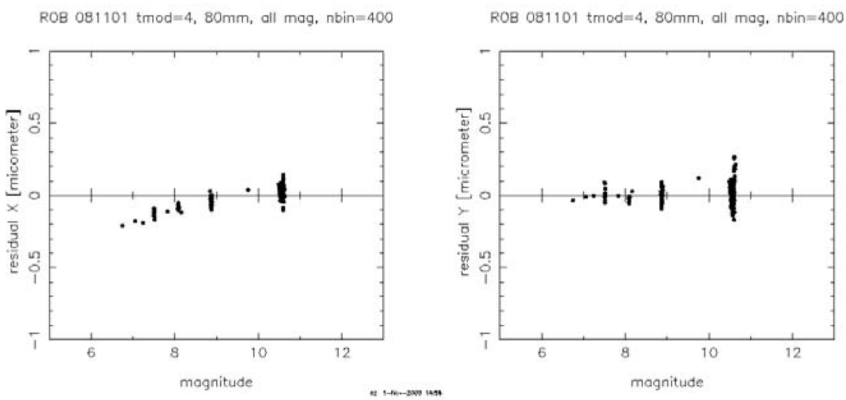

Figure 2.: As part of the machine calibration, a small systematic position error as function of magnitude is found from the direct-reverse measures of the grid plate. Corrections can now be applied to program plate measures.

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